



Europäisches Patentamt

(19)

European Patent Office

(11) Publication number:

Office européen des brevets

0 226 039

A1

(12)

## EUROPEAN PATENT APPLICATION

(21) Application number: 86115640.4

(51) Int. Cl. F04D 19/04 , F04D 25/16

(22) Date of filing: 11.11.86

(30) Priority: 13.11.85 JP 252711/85

(71) Applicant: HITACHI, LTD.  
6, Kanda Surugadai 4-chome Chiyoda-ku  
Tokyo 100(JP)

(43) Date of publication of application:  
24.06.87 Bulletin 87/26

(72) Inventor: Nagaoka, Takashi  
Tsukuba House 9-503 2625-3 Oaza  
Shimoinayoshi  
Chiyodamura Niihari-gun Ibaraki-ken(JP)  
Inventor: Mase, Masahiro  
509, Oaza Marubayashi Nogimachi  
Shimotsuga-gun Tochigi-ken(JP)  
Inventor: Gyobu, Ichiro  
2472-119, Oaza Anjiki Dejimamura  
Niihari-gun Ibaraki-ken(JP)  
Inventor: Ikemura, Kazuhiko Hitachi Komeiryo  
3745-2, Oaza Shimoinayoshi Chiyodamura  
Niihari-gun Ibaraki-ken(JP)

(84) Designated Contracting States:  
CH DE FR LI

(74) Representative: Finck, Dieter et al  
Patentanwälte v. Flöner, Ebbinghaus, Finck  
Marienhilfplatz 2 & 3  
D-8000 München 90(DE)

### (54) Vacuum pump apparatus.

(57) A vacuum pump apparatus of a unitary construction type has a plurality of pump stages of different types arranged in a housing (4) and between suction (2) and discharge ports (3) therein. The apparatus further has a gas passage (17) for introducing a gas having a molecular weight higher than that of the gas sucked through the suction port (2) into a pump stage spaced downstream from the suction port (2) by more than one pump stage. The compression ratio across the pump stage into which the gas of the higher molecular weight is introduced is increased to enable the pump of an upstream stage to operate with a required discharge pressure, whereby a high level of vacuum can be established at the suction port (2) of the vacuum pump apparatus.

EP 0 226 039 A1

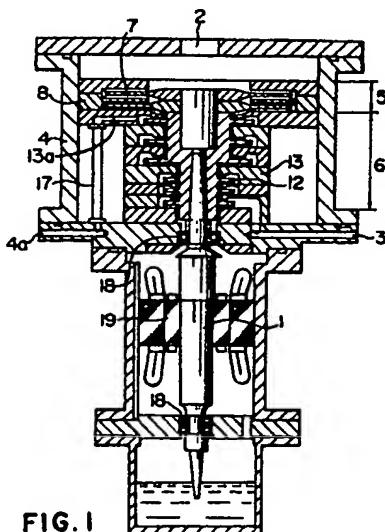


FIG. I

## VACUUM PUMP APPARATUS

## BACKGROUND OF THE INVENTION

## FIELD OF THE INVENTION

The present invention relates to a vacuum pump apparatus of the type in which the discharge side of the pump is maintained at the atmospheric pressure. More particularly, the present invention is concerned with a vacuum pump apparatus of unitary construction type which is capable of producing a high level of vacuum at its suction side when used in sucking gases having small molecular weights, such as hydrogen, helium, and so forth.

## DESCRIPTION OF THE PRIOR ART

High levels of vacuum are often required in various field of technology such as nuclear fusion, semi-conductor manufacture, electron-microscopic examination, and so on. Hitherto, turbo molecular pump apparatus, which exhibit superior throughput characteristics in the molecular flow region, have been used for establishing such high levels of vacuum. Unfortunately, however, the turbo molecular pump apparatus have a drawback that the throughput characteristics of this type of pump largely depends on the pressure at the discharge side thereof. For instance, in order that a turbo molecular pump apparatus may create the required high level of vacuum, it is necessary that a high vacuum on the order of  $10^{-2}$  to  $10^{-3}$  Torr. has to be maintained at the discharge side of this pump. To this end, an auxiliary vacuum pump is required so as to establish a high vacuum at the discharge side of the molecular pump in advance of the operation of the molecular pump. Usually, a rotary vacuum pump is used as the auxiliary vacuum pump.

In consequence, the overall size of the vacuum pump apparatus incorporating a turbo molecular pump is increased and the control of such apparatus is complicated due to the present of the auxiliary vacuum pump. This undesirably limits the use of a turbo molecular pump which inherently is capable of establishing a high level of vacuum.

This in turn gives rise to a demand for a vacuum pump apparatus of unitary construction type in which a turbo molecular pump is combined with other types of vacuum pump. An example of such a vacuum pump apparatus as of unitary construction type is disclosed in United States Patent No. 3,969,039. This pump has a plurality of stages: namely, a first stage constituted by an axial turbo-molecular pump, a second stage constituted by a

spiral molecular drag pump, a third stage constituted by a centrifugal compressor, and a final stage constituted by a vortex diode pump. These stages are arranged in series within a common housing and between suction and discharge ports of the unitary-construction type vacuum pump.

The centrifugal compressor stage and the vortex diode pump stage operate in the viscous flow region of a gas. Provided that the factors such as the shapes of impellers, vanes and so forth, as well as the rotational speed of a shaft, are the same, the compression ratio between the centrifugal compressor stage and across the vortex diode pump stage vary depending on the molecular weight of the gas flowing through these pumps. In general, the greater the molecular weight, the greater the compression ratio and, the smaller the molecular weight, the smaller the compression ratio.

In the prior art vacuum pump apparatus of the unitary-construction type referred to above, therefore, a high compression ratio is obtained across the centrifugal compressor stage and across the vortex diode pump stage particularly when a gas sucked through the suction port has a large molecular weight as in the case of nitrogen, air, and so forth. In such a case, the axial turbo-molecular pump and the spiral molecular drag pump, which are disposed upstream of the centrifugal compressor stage, can operate in an intermediate flow region or molecular flow region, so that a high level of vacuum is established at the suction port of the vacuum pump.

However, when the gas sucked by the vacuum pump has a small molecular weight as in the case of hydrogen or helium, the compression ratio across the stages constituted by the centrifugal compression pump and the vortex diode pumps is so small that the axial turbo-molecular pump and the spiral molecular drag pump disposed upstream thereof are obliged to operate in the viscous flow region rather than in the intermediate or molecular flow region. In such a case, the compression ratio across the vacuum pump is too small accordingly. That is, the vacuum pump apparatus cannot establish the desired very level of vacuum when it is used for sucking a gas having a comparatively small molecular weight. The prior art has not paid any attention to this point.

## SUMMARY OF THE INVENTION

According to one feature of the present invention, there is provided a vacuum pump apparatus having a plurality of pump stages of different types arranged in series between suction and discharge ports of a housing and a gas passage means through which a gas different from the gas sucked through the suction port is introduced into the pump stage which is spaced downstream from the suction port by more than one pump stage.

According to another feature of the invention, there is also provided a vacuum pump apparatus having a plurality of pump stages of different types arranged in series between suction and discharge ports in a housing and a gas passage means through which a gas different from the gas sucked through the suction port is introduced into the pump stage which operates in viscous flow region.

By these features of the present invention, because a gas having a greater molecular weight can be introduced through the gas passage into an intermediate pump stage, it is possible to obtain a large compression ratio across each pump stage and, thus, establish a high level of vacuum at the suction port of the vacuum pump apparatus even when the gas sucked through the suction port has a small molecular weight.

The above and other objects, features and advantages of the present invention will be made more apparent by the following description with reference to the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an axial sectional view of an embodiment of a vacuum pump apparatus in accordance with the present invention;

Fig. 2 is an enlarged fragmentary view of an essential portion of a centrifugal compression pump stage in the vacuum pump apparatus embodying the present invention;

Fig. 3 is an end view of an impeller of the centrifugal compressor stage taken in the direction of an arrow III shown in Fig. 2;

Fig. 4 is an end view of a stationary disk in the centrifugal compressor stage taken in the direction of an arrow IV shown in Fig. 2;

Fig. 5 is an enlarged fragmentary sectional view of an essential portion of a circumferential-flow compression pump stage incorporated in the vacuum pump apparatus embodying the present invention;

Fig. 6 is an end view of an impeller of the circumferential-flow compression pump taken in the direction of an arrow VI in Fig. 5;

Fig. 7 is an end view of a stationary disk of the circumferential-flow compression pump taken in the direction of an arrow VII in Fig. 5;

Fig. 8 is an axial sectional view of another embodiment of the vacuum pump apparatus in accordance with the present invention;

Fig. 9 is an enlarged fragmentary sectional view of an essential portion of a spiral molecular drag pump incorporated in the vacuum pump apparatus embodying the present invention; and

Fig. 10 is a plan view of a stationary disk of the spiral molecular drag pump shown in Fig. 9.

## 15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the vacuum pump apparatus of the present invention will be described hereinunder with reference to the accompanying drawings.

Referring first to Fig. 1 which is an axial sectional view of an embodiment of the vacuum pump apparatus of the invention, a rotary shaft 1 extends through a housing 4 having a suction port 2 and a discharge port 3. The shaft 1 is rotatably supported by the housing 4 through bearings 18 and is connected at its lower end to a motor 19. A centrifugal compressor stage 5 and a circumferential-flow pump stage 6 are arranged in series in the housing 4 between the suction port 2 and the discharge port 3.

The centrifugal compressor stage 5 has open-type impellers 7 mounted on the shaft 1 and stationary disks 8 which are fixed to the inner surface of the housing 4. The impellers 7 and the stationary disks 8 are arranged alternately in the axial direction. As will be seen in Figs. 2 to 3, each impeller 7 has one side provided with a plurality of vanes 9 which are curved such that they progressively approach the axis of rotation of the impeller 7 as viewed in the direction of rotation. Similarly, as will be seen in Figs. 2 and 4, each stationary disk 8 is provided with a plurality of stationary vanes 10 which are formed on the surface thereof which faces the rear surface of the adjacent impeller 7, i.e., the surface of the impeller 7 having no vane. The stationary vanes 10 also are curved such that they progressively approach the axis of rotation as viewed in the direction of rotation of the impeller 7.

As shown in Figs. 5 to 7, the circumferential-flow pump stage 6 has a plurality of impellers 12 mounted on the shaft 1 and a plurality of stationary disks 13 fixed to the inner surface of the housing 4. The impellers 12 and the stationary disks 13 are arranged alternately in the axial direction. Each impeller 12 has one side provided with a plurality

of radial vanes 11 formed in its radially outer peripheral zone, while each stationary disk 13 is provided with a circumferentially extending groove 14 of a U-shaped section formed in the surface thereof facing the radial vanes 11 on an adjacent impeller 12. As shown in Figs. 5 and 7, a port 15 is formed in each stationary disk 13 at one terminal end of the U-shaped groove 14. The port 15 and the groove 14 constitute a gas passage 16.

A reference numeral 17 designates a member such as a pipe which provides a communication between a gas inlet 4a formed in the housing 4 and a port 13a formed in the stationary disk 13 of the first stage of the circumferential-flow pump stage 6. The arrangement is such that a gas of a small molecular weight which is to be pumped by the vacuum pump apparatus is sucked through the suction port 2, while another kind of gas having a greater molecular weight is introduced into the inlet side of the circumferential-flow pump stage 6 from the gas inlet 4a in the housing 4 through the pipe 17.

In operation, when the gas sucked through the suction port 2 has a large molecular weight as in the case of air or nitrogen, the circumferential-flow compression pump stage 6 operates in the viscous flow region so that a large compression ratio is obtained across each stage of the circumferential-flow compression pump 6. In consequence, a high level of vacuum, say less than several Torr., is established at the inlet side of the circumferential-flow compression stage 6. This in turn causes the centrifugal compressor stage 5 to operate as a spiral molecular drag pump in the intermediate flow region or molecular flow region so as to develop a large pressure difference across this stage. Consequently, a very high level of vacuum on the order of  $10^{-3}$  to  $10^{-4}$  Torr. is established at the inlet port 2 of the vacuum pump apparatus.

On the other hand, when the gas sucked through the suction port 2 of the vacuum pump apparatus has a small molecular weight as in the case of hydrogen, helium or the like, only a small compression ratio is developed across the circumferential-flow compression pump stage 6, so that the pressure at the inlet side of the circumferential-flow compression pump stage is as high as several tens to several hundreds of Torr. In this case, the centrifugal compressor stage 5 also operates in the viscous flow region, so that it cannot work as the spiral molecular drag pump. This means that the compression ratio obtained across the centrifugal compressor stage is not so large, with the result that the pressure at the suction port 2 of the vacuum pump apparatus is still as high as several to several tens of Torr.

A description will be made hereinunder as to the reason why the vacuum pump apparatus fails to create a high level of vacuum when the pumped gas has a small molecular weight.

Generally, when a centrifugal compressor and a circumferential-flow compression pump operate in the viscous flow region, these pumps function as compressors of turbine type, and the following relationship exists between the compression ratio  $\pi$  and adiabatic head Had:

$$\pi = \left( \frac{K-1}{K} \frac{M}{R_0 T} Had + 1 \right)^{\frac{K}{K-1}}$$

where M represents the molecular weight,  $R_0$  represents the general gas constant, K represents the specific heat ratio and T represents the temperature of the gas. The adiabatic head Had is constant regardless of the kind of the gas, provided that the shapes, sizes and the speeds of the impellers and stationary disks are unchanged. However, because the molecular weight W and the specific heat ratio K vary depending on the kind of the gas, the compression ratio is changed in accordance with the kind of the gas. For instance, the molecular weight and the specific heat ratio of air are 29 and 1.4, respectively, while those of helium gas are 4 and 1.67, respectively. It is assumed here that a compression pump stage can produce a compression ratio of 2 when it compresses air at 20°C. If the same pump stage is used for helium gas, the compression ratio is as small as 1.11. Assuming that a vacuum pump system is constituted by 8 (eight) such stages and that the discharge pressure is the atmospheric pressure, the pressure levels at the suction side of the vacuum pump system are 3 Torr. for air and 300 Torr. for helium gas. Thus, the conventional vacuum pump system could not provide very high degree of vacuum when used for pumping gases of small molecular weights.

In the described embodiment of the invention, this problem is overcome by introducing a gas of a larger molecular weight than the gas sucked through the suction port 2, e.g., nitrogen or air into one of the compression pump stages which is spaced downstream from the suction port 2 by more than one stage, i.e., into the circumferential-flow compression pump stage 6, through the pipe 17 connected between the gas inlet 4a provided in the wall of the housing 4 and the inlet port 13a in the stationary disk 13 of the first stage of the circumferential-flow compression pump stage 6. The gas having large molecular weight advanta-

geously increases the compression ratios across subsequent stages, so that a high degree of vacuum is established at the suction side of the vacuum pump apparatus.

Namely, the gas of the larger molecular weight introduced through the pipe 17 causes the circumferential-flow compression pump stage 6 to operate in the viscous flow region, so that the pressure at the inlet side of this pump stage 6 can be lowered to several Torr. This in turn permits the centrifugal compression pump stage 5 to operate in the intermediate or molecular flow region, so that the pressure at the suction side of this pump stage 5 can be lowered to a high degree of vacuum on the order of  $10^{-2}$  to  $10^{-3}$  Torr. It is thus possible to create the desired high degree of vacuum even when the gas pumped by the vacuum pump apparatus has a small molecular weight.

The reason why a gas which has a greater molecular weight than that of the gas sucked through the suction port of the vacuum pump apparatus is introduced into the pump stage which inherently operates in the viscous flow region will be described hereinunder. If a gas supplied to the pump stage which inherently operates mainly in the viscous flow region has a small molecular weight, the pump stage which inherently operates in the intermediate or molecular flow region cannot provide a required high compression ratio. On the other hand, if a gas having a large molecular weight is introduced into the pump stage which inherently operates in the intermediate or molecular flow region, the pump stage provides a large compression ratio. However, the flow through this pump stage becomes to be equal to the total of the amount of the gas supplied and the amount of the gas discharged, with a result that the pumping effect of this pump stage is lowered undesirably. It will be understood that, by supplying a gas of a large molecular weight in the viscous flow region, it is possible to enable the pump stage to operate to pump a gas of small molecular weight with a large compression ratio and a high efficiency.

Figs. 8 to 10 show another embodiment of the vacuum pump apparatus according to the present invention. This embodiment comprises a first pump stage constituted by a spiral molecular drag pump 20, an intermediate stage constituted by a centrifugal compression pump or compressor 5 and a final stage constituted by a circumferential-flow compression pump 6. The pump stages are arranged between the suction port 2 and the discharge port 3 within the housing 4. A gas passage 17 provides a communication between a gas inlet 4a formed in the housing 4 and the inlet side of the centrifugal compressor stage 5. The constructions

of the centrifugal compressor stage 5 and the circumferential-flow compression pump stage 6 are the same as those in the first embodiment and, therefore, detailed description thereof is omitted.

5 The spiral molecular drag pump 20 has rotary disks 21 fixed to the rotary shaft 1 and stationary disks 22 fixed to the inner surface of the housing 4. The rotary disks 21 and the stationary disks 22 are arranged alternately in the direction of the axis of the rotary shaft 1. Each of the stationary disks 22 is provided with a spiral groove 23 formed in the surface thereof facing the adjacent rotary disk 21.

10 The gas passage 17 may alternatively be connected to the inlet side of the circumferential-flow compression pump stage 6 constituting the final stage, rather than to the inlet side of the centrifugal compressor stage 5 as in the illustrated embodiment.

15 In operation, when the gas sucked through the suction port 2 of the vacuum pump apparatus has a small molecular weight, another gas of a larger molecular weight is simultaneously introduced into the inlet side of the centrifugal compressor stage 5 through the gas passage 17. In consequence, the centrifugal compressor stage 5 and the circumferential-flow compression pump stage 6 are allowed to operate in the viscous flow region and thus produce large compression ratios across these stages, so that the pressure at the inlet side of the centrifugal compression pump stage 5 is lowered to several Torr. This in turn enables the spiral molecular drag pump 20 to operate in the intermediate or molecular flow region so as to establish a desired high degree of vacuum, say 20  $10^{-2}$  to  $10^{-3}$  Torr, at the inlet side thereof, i.e., at the suction side of the vacuum pump apparatus.

25 As has been described, according to the invention, each pump stage of the vacuum pump apparatus can produce large compression ratio due to introduction of a gas having a large molecular weight into an intermediate or final pump stage, so that a high degree of vacuum can be obtained at the suction side of the vacuum pump apparatus even when a gas sucked through the suction port 40 has a small molecular weight.

#### Claims

- 50 1. In a vacuum pump apparatus having a plurality of pump stages of different types arranged within a housing and between suction and discharge ports in said housing to suck a gas through said suction port and discharge compressed gas through said discharge port, the improvement which comprises a gas passage means for introducing a gas different from the gas sucked

through said suction port into a pump stage spaced downstream from said suction port by more than one stage.

2. A vacuum pump according to Claim 1, wherein said plurality of pump stages comprise a combination of a centrifugal compressor stage adjacent to said suction port and a circumferential-flow compression pump stage downstream of said centrifugal compression pump stage, and said gas passage means is arranged to provide a communication between the exterior of said housing and an inlet side of said circumferential flow compression pump stage.

3. A vacuum pump apparatus according to Claim 1, wherein said plurality of pump stages comprise a combination of a spiral molecular drag pump stage adjacent to said suction port, a centrifugal compressor stage downstream of said spiral molecular drag pump and a circumferential-flow compression pump stage downstream of said centrifugal compressor stage, and said gas passage means is arranged to provide a communication between the exterior of said housing and an inlet side of at least said centrifugal compressor stage.

4. A vacuum pump apparatus according to Claim 1, wherein said gas introduced through said gas passage means has a molecular weight greater than that of said gas sucked through said suction port.

5. In a vacuum pump apparatus having a plurality of pump stages of different types arranged within a housing and between suction and discharge ports in said housing to suck a gas through said suction port and discharge compressed gas through said discharge port, said pump stages including a pump stage of a type that operates in the viscous flow region, the improvement which comprises a gas passage means for introducing a gas different from the gas sucked through said suction port into said pump stage which operates in the viscous flow region.

5

10

15

20

25

30

35

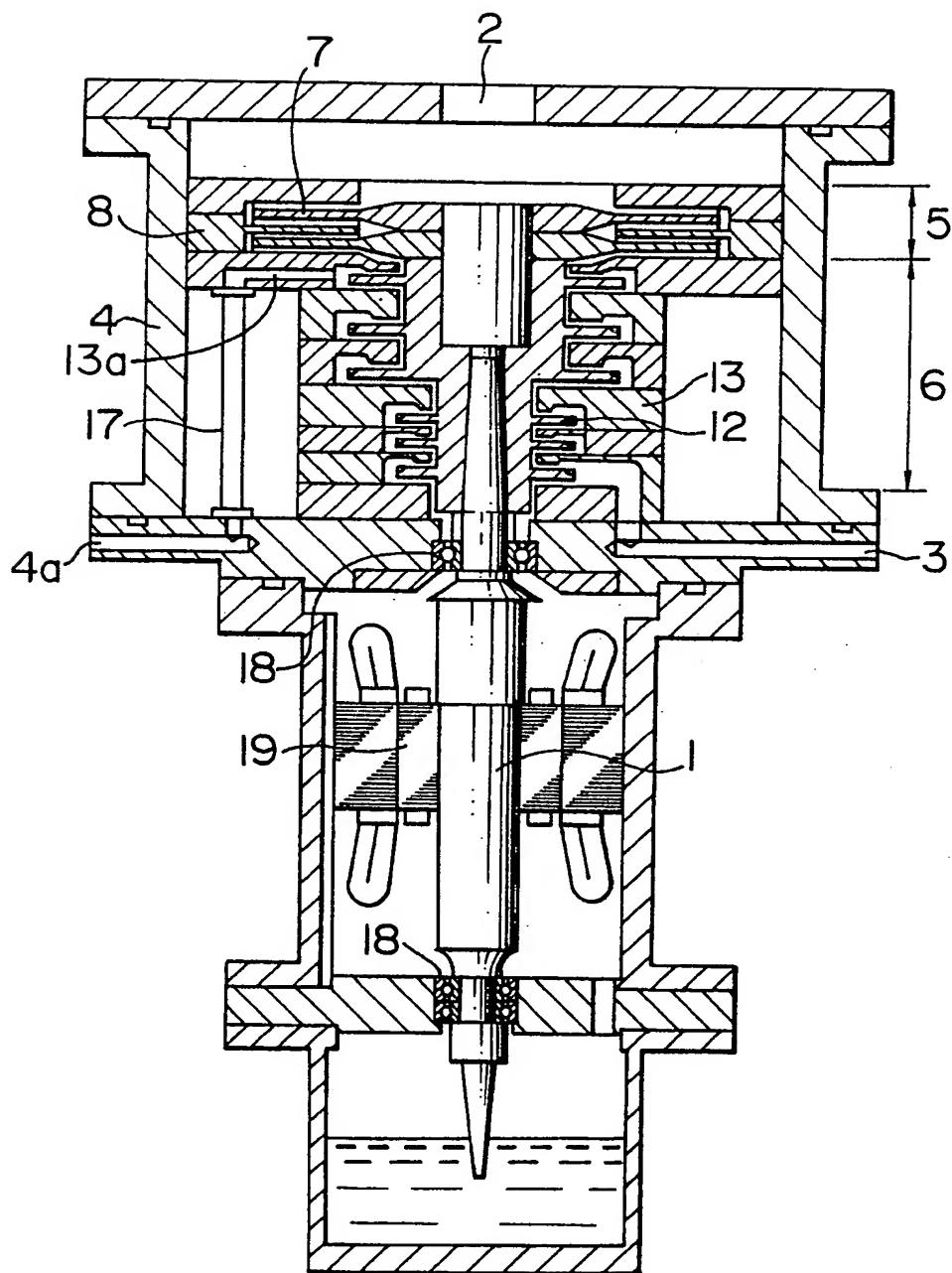
40

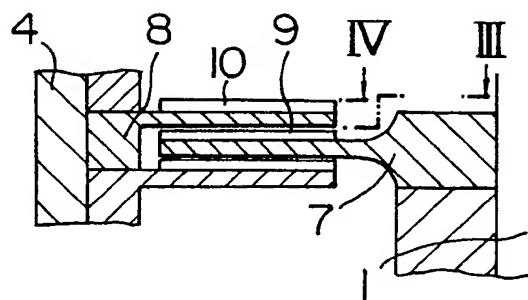
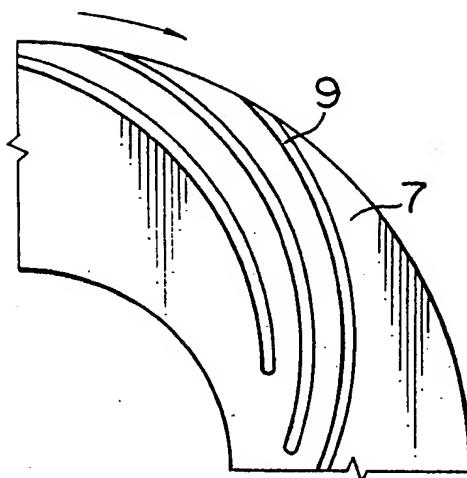
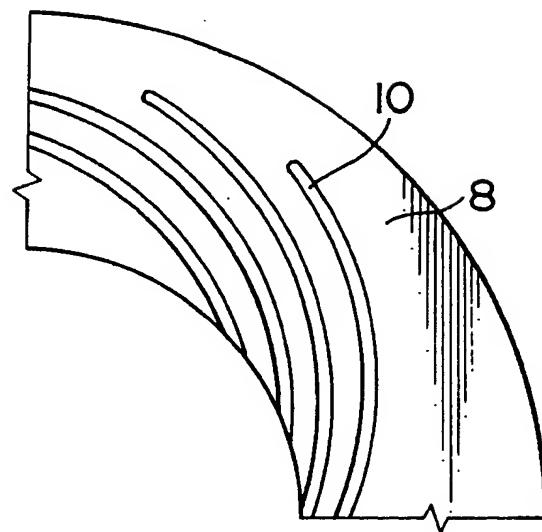
45

50

55

FIG. I



**FIG. 2****FIG. 3****FIG. 4**

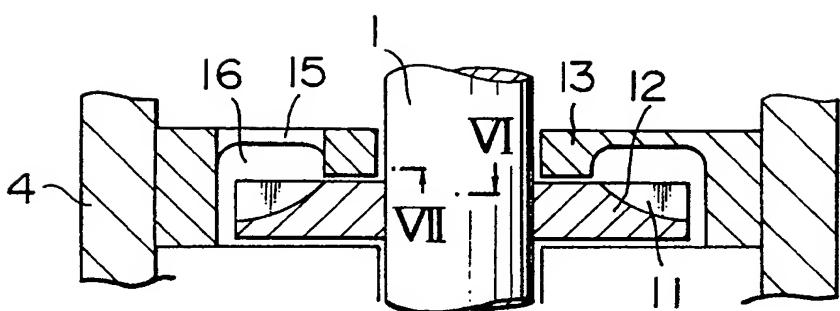
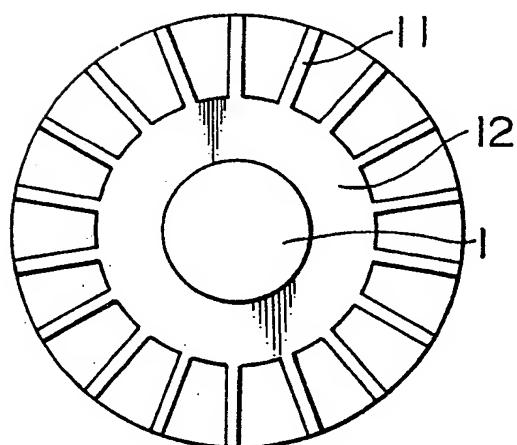
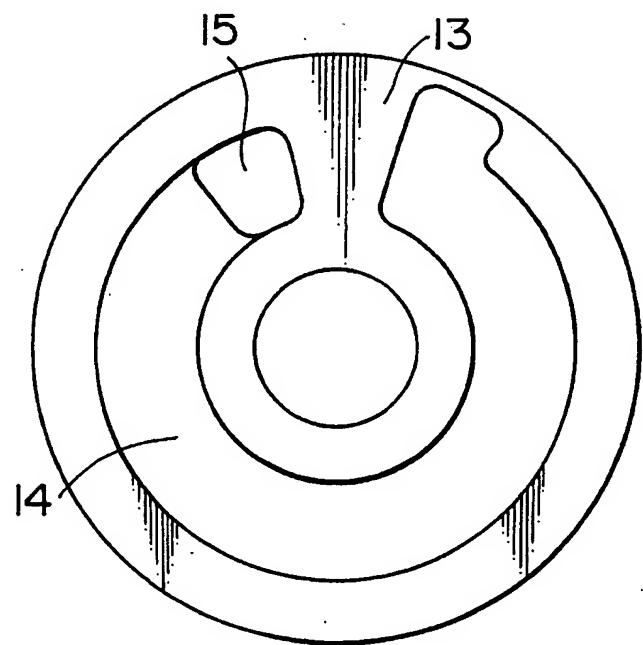
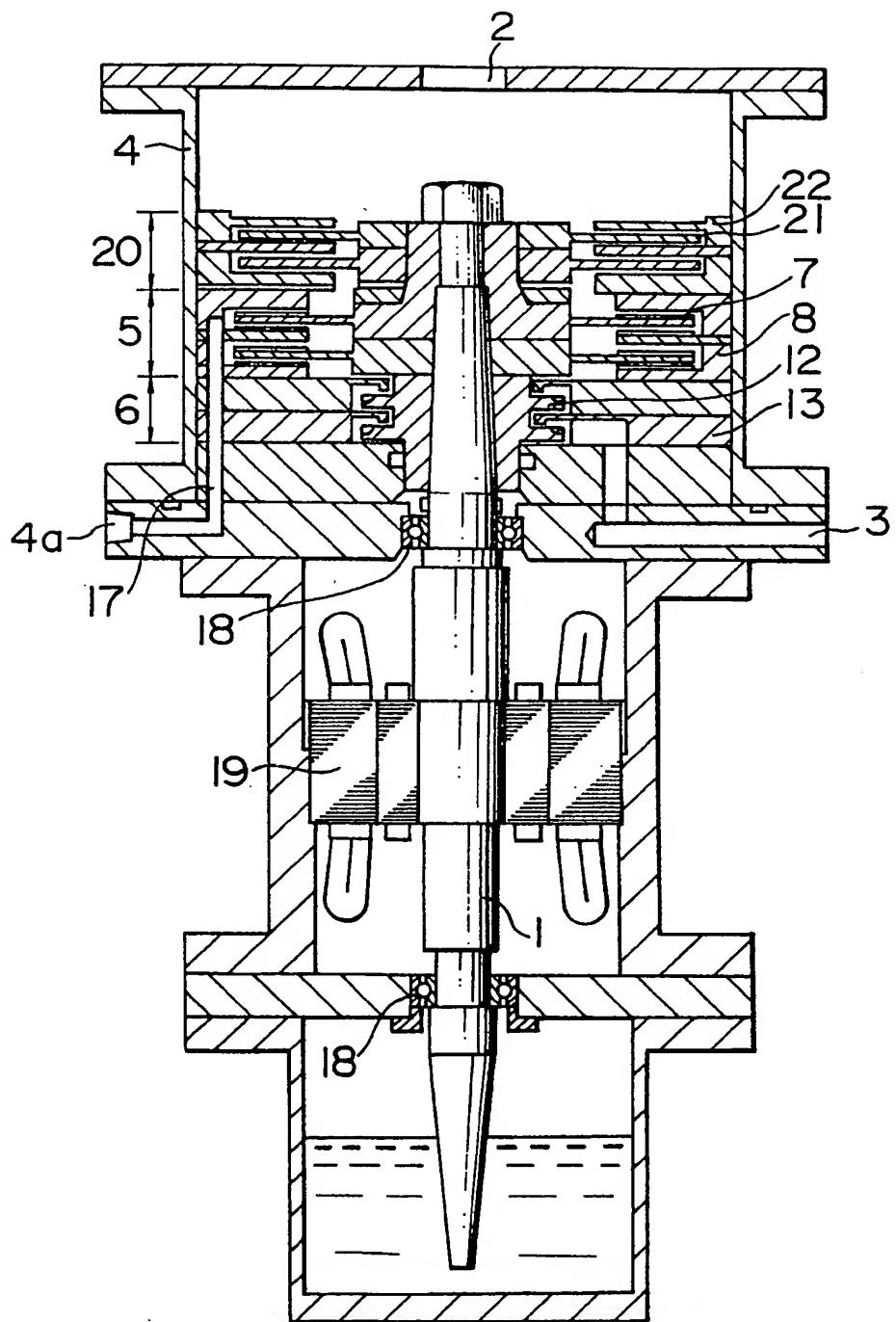
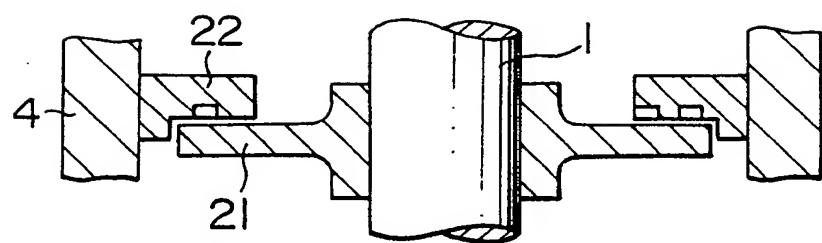
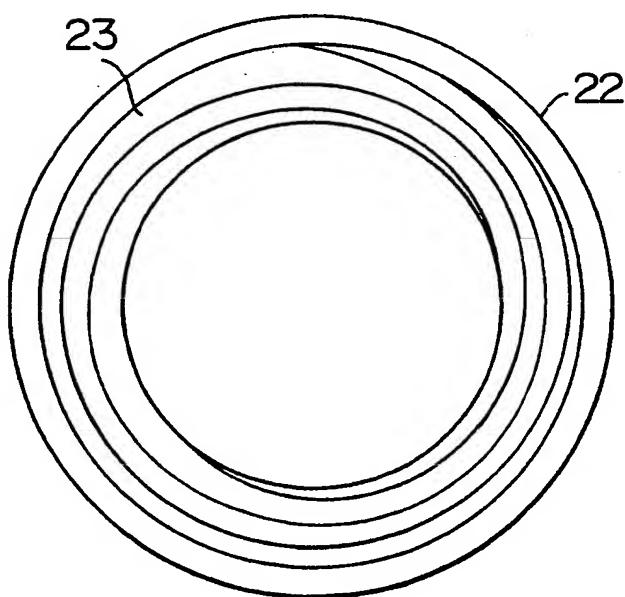
**FIG. 5****FIG. 6****FIG. 7**

FIG. 8



**FIG. 9****FIG. 10**



**EUROPEAN SEARCH REPORT**

EP 86 11 5640

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	DE-A-2 526 164 (LEYBOLD-HERAEUS) * Figure 1; page 2, paragraph 3; page 3, paragraph 1; claim 1 *	1,4,5	F 04 D 19/04 F 04 D 25/16
X	DE-A-2 507 430 (E.J. SCHITTKE) * Whole document *	1,4,5	
Y	---	2	
Y	EP-A-0 143 684 (BERTIN & CIE) * Figure 2; page 2, line 28 - page 3, line 10; page 5, line 29 - page 6, line 4; claim 1 *	2	
A	DE-A-2 408 257 (LEYBOLD-HERAEUS) * Figures 1,2; page 1, paragraphs 2,3; claims 1,2 *	1,4,5	TECHNICAL FIELDS SEARCHED (Int. Cl.4)
	-----		F 04 D
The present search report has been drawn up for all claims			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	23-02-1987	TEERLING J.H.	
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone	T : theory or principle underlying the invention		
Y : particularly relevant if combined with another	E : earlier patent document, but published on, or		
document of the same category	after the filing date		
A : technological background	D : document cited in the application		
O : non-written disclosure	L : document cited for other reasons		
P : intermediate document	& : member of the same patent family, corresponding		
document			